Neutralino annihilation γ-rays from clumps and the LMC

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Abstract

We discuss the detectability of dark matter clumps in the Milky Way halo due to neutralino annihilation. We then focus on a known "clump", the Large Magellanic Cloud (LMC).

Key words: LMC, γ-rays, neutralino annihilation, EGRET, GLAST, ACTs

1 Dark matter clumps

High resolution N-body simulations have revealed the survival of considerable substructure within galactic halos. Assuming these substructure clumps are composed of annihilating neutralinos, the flux F of a clump at distance d with a density distribution $\rho(r)$ is

$$F = \frac{1}{2}\frac{1}{4\pi d^2}\frac{N_\gamma\langle\sigma v\rangle}{m_\chi^2}\int\limits_0^R \rho^2(r)d^3r, \tag{1}$$

where $\langle\sigma v\rangle$ is the thermally averaged annihilation cross section, m_χ is the neutralino mass, and N_γ is the number of photons per annihilation with energy above an assumed energy threshold. For the density profile of the clumps we use the Navarro, Frenk, and White (1996) (NFW) and the Moore et al. (1998) profiles which were found to describe adequately the dark matter halos in simulations. As an upper limit to the degree of central concentration

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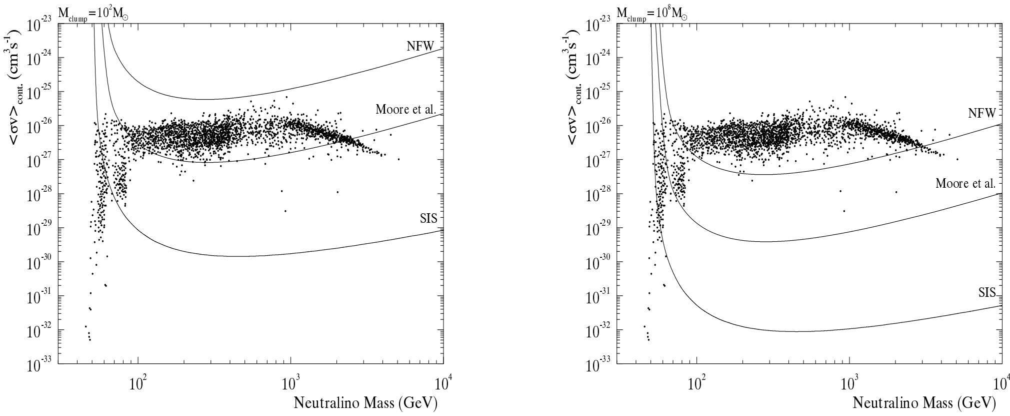

Fig. 1. The minimum detectable $\langle\sigma v\rangle_{cont.}$ versus m_χ for the SIS, the Moore et al., and the NFW profile. The clump masses used are $10^2 M_\odot$ (left panel) and $10^8 M_\odot$ (right panel). The dots represent possible SUSY models. The lines represent the 5-σ detection limits. Only SUSY models that lie above the corresponding curve will yield a detectable signal.

of the actual clump profile we also consider the singular isothermal sphere (SIS). The three profiles behave at the center as r^{-1}, $r^{-1.5}$, and r^{-2}, respectively. The results for the profiles and for the minimum and maximum clump masses used, are shown in Fig. 1. The SUSY models that give a 5-σ (or more) detection using an Atmospheric Cherenkov Telescope (ACT) with effective area $A_{eff} = 10^8\text{cm}^2$, energy threshold $E_{th} = 50$ GeV, and 100 hours of observation, are all the models that lie above the corresponding line for each density profile. The backgrounds used to calculate the noise are the hadronic and electronic cosmic ray shower contributions. Clearly, massive clumps appear to be easily detectable, regardless of profile; less massive clumps may be detectable, depending on their degree of central concentration. For more details see Tasitsiomi and Olinto (2002). There are some issues with respect to the ability of dark matter clumps to survive tidal disruption at distances small enough to yield easily detectable fluxes. In addition, there are some observational issues, given that the exact location of these clumps is not known. Thus, we focus on an object whose location is known, the LMC.

2 Flux from the LMC

We derive the density profile needed to calculate the γ-ray flux using rotation velocity data (Kim et al., 1998; Alves and Nelson, 2000). We fit the data using both the NFW (ρ_{NFW}), and the Hayashi et al. (2003) profile (ρ_H),

$$\rho_{NFW} = \frac{\rho_0}{r/r_s(1+r/r_s)^2} \ , \quad \rho_H = \frac{\rho_{NFW}}{1+(r/r_t)^3} \quad . \tag{2}$$

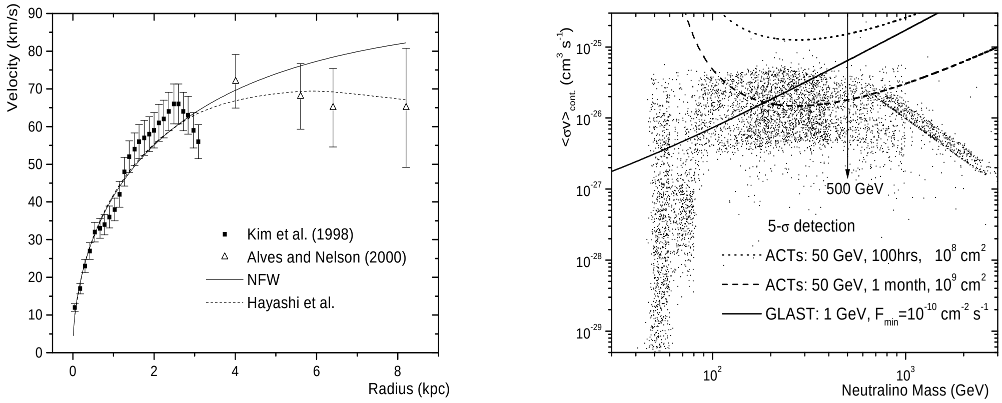

Fig. 2. Left panel: The LMC rotation curve (points) and the NFW and Hayashi et al. fits. Right panel: The minimum detectable $\langle \sigma v \rangle_{cont.}$ versus m_χ for the Hayashi et al. profile (the NFW yields similar results). Only SUSY models that lie above the corresponding curve yield a detectable signal. The dotted line represents an observation feasible with upcoming ACTs. The dashed line assumes an effective area of 10^9cm^2 which will be achieved only at high energy thresholds ($\sim$ 1 TeV); this along with the relatively large integration time, renter this observation rather difficult to be achieved. The F_{min} used for GLAST corresponds to one year of on-target observation and is the GLAST flux sensitivity for energies $\geq$ 1 GeV. The vertical arrow at $m_\chi = 500$ GeV corresponds to a recently derived upper limit on the neutralino mass(Ellis et al., 2003).

Numerous observations indicate that the LMC is tidally stripped. The Hayashi et al. profile is a modification of the NFW which accounts for the tidal stripping that a halo may have undergone.

The fits are shown in the left panel of Fig. 2. In the right panel we present our results for the part of the SUSY parameter space that gives a 5-σ detection for GLAST and a typical ACT; the instrument and observation parameters used to derive these results are also shown. Requiring that $F_{LMC} \geq F_{min}^{GLAST} = 10^{-10}$ cm^{-2} s^{-1} we find that GLAST will be able to detect the signal for a significant part of the parameter space. This is true especially if the recently derived limit $m_\chi < 500$ GeV is taken into account(Ellis et al., 2003). Assuming standard specifications, ACTs will not be able to probe any part of the parameter space (dotted line). Unless, large integration times (say, $\sim$ 1 month) and effective areas (say, $\sim 10^9$ cm^2) are used (dashed line). Note though that such integration times are fairly long for ACT observations, and that such large effective areas for an energy threshold $\sim$ 50 GeV are beyond the goals of existing and upcoming ACTs. These conclusions remain essentially the same for all the profiles used to model the LMC halo. The spectrum and its characteristic features, such as the cutoff at $E = m_\chi$ will be useful in identifying neutralino annihilation as the origin of the observed flux, especially in the case of GLAST where the prospects of detection are fairly good. The monochromatic lines

produced by neutralino annihilation (e.g., the $\gamma\gamma$ line at $E = m_\chi$) would be excellent observational signatures if the cross sections for these processes were not suppressed(Tasitsiomi and Olinto, 2002).

EGRET has detected a flux of $(14.4 \pm 4.7) \times 10^{-8}$ photons ($E > 100$ MeV) cm^{-2} s^{-1} from the LMC (Hartman et al., 1999). The emission due to neutralino annihilation can be anywhere from $\sim 10^{-13}$ to $\sim 10^{-9}$ photons ($E >$ 100 MeV) cm^{-2} s^{-1}, depending on the neutralino parameters. The maximum possible flux is still ~ 2 orders of magnitude less than the observed flux. This means that cosmic rays may be almost the exclusive source of the observed flux, as is often assumed. This is verified in the case of synchrotron emission from neutralino annihilation as well [for the synchrotron and for more details on the γ-rays see Tasitsiomi, Gaskins, and Olinto (2003)].

3 Conclusions

Dark matter clumps are in principle detectable, depending on the SUSY parameters, their distance and their degree of central concentration. The expected γ-ray flux from the LMC is, for most SUSY models, significantly smaller than what EGRET observed, verifying the usual assumption that cosmic rays are almost exclusively the origin of the detected flux. However, the flux is high enough to renter a large part of the SUSY parameter space accessible to GLAST; the detection of the signal by ACTs is highly unlikely.

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